

# Design and Analysis of a New Topology for Bidirectional Converter in Flywheel Energy Storage System

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**ABSTRACT:** A bidirectional converter (BDC) is required in areas where generated energy is stored. Some of the application areas are uninterruptible power system, transportation, flywheel energy storage systems, etc. Bidirectional flow of power using buck mode and boost mode along with efficiency and high power density is important need of such systems. This report proposes a new topology of BDC with the help of Silicon Controlled Rectifier (SCR) and insulated-gate bipolar transistor (IGBT) with a new control logic to get zero switching losses by using zero voltage transition (ZVT) and zero current transition (ZCT) methods. The proposed method make sure zero switching power loss (ZSPL) for buck mode as well as boost mode for BDC. The method is easy to implement and it can achieve ZSPL for both switch-on and switch-off of the main devices leading to improved efficiency. The principle of operation, design procedure and analysis, are explained for buck mode and boost mode of the proposed topology.

**KEYWORDS:** Bidirectional converter, flywheel energy storage system, zero current transition, zero voltage transition.

## I. INTRODUCTION

A bidirectional converter (BDC) is a fundamental component of practices where energy storage gadgets are utilized. This report concentrates on one of the applications where flywheel is utilized as the energy stockpiling gadget. A regular Flywheel Energy Storage (FES) framework is given in Fig. 1. The machine's rotor is attached to the flywheel. A brushless dc machine (BLDC) has been utilized. The connection of BLDC with the flywheel will be called as "FES machine" from this point onwards. The flywheel rotating Using the consumed energy from DC bus, rotation of flywheel is started; the BDC behaves as a buck converter and this operation is called as buck mode or motoring mode. When the supply is cut off, energy discharge in flywheel takes place. This operation is called as generation mode or boost mode. Here, the BDC behaves as boost converter.

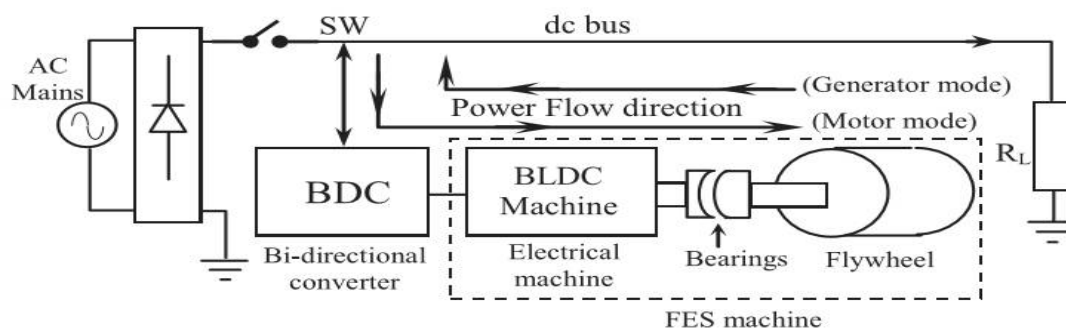


Fig.1. FES system

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For such systems, the main necessities are High energy density and energy efficiency. By high frequency switching, high energy densities can be obtained. By reducing losses, High energy efficiency can be obtained. The effective losses across BDC are mainly due to switching losses in FES system. These type of losses can be made low by method of zero voltage switching (ZVS) or zero current switching (ZCS) by making the value of voltage zero while turning on or the current is zero while turning off. The resonant part of the circuit is in series with the main switching device for ZVS/ZCS method, whereas, the resonant part of circuit is not in the series with the main switching device. Actually, resonant circuit is in the picture only at transition period (ON state to OFF state and OFF state to ON state). Therefore, we can say ZVT/ZCT techniques are very well suited for the applications involving pulse width modulation (PWM). The current flowing through device under switching becomes negative during ZCT technique which makes this technique a “true-zero” switching power loss (ZSPL).

A ZSPL technique for BDC proposed herein this paper that leads to enhanced efficiency. In this technique, the components used are IGBTs which will act as main device which carry load current and SCRs which acts as a auxiliary device. BDCs used in electrical energy storage applications are inherently DC–DC converters and they could be isolated type or non-isolated. A BDC comprises of two switches. One switch is for voltage step down and allows the power to flow from the DC bus to FES, the second switch is utilized for voltage-boost allowing the power to flow from FES to DC bus.

## II. RELATED WORK

The block diagram of the proposed topology is shown in fig. 2. It consists of Rectifier stage, Bidirectional converter and Flywheel energy system (FES). Rectifier converts AC to DC. Bidirectional converter uses IGBT and SCRs to transfer energy to and from FES. FES comprises of Flywheel coupled to electrical machine.

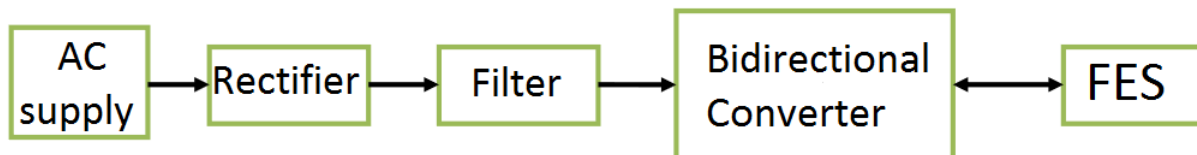


Fig. 2 Block diagram of Flywheel Energy Storage System

In this technique, the components used are IGBTs which acts as main device and SCRs which acts as a auxiliary device. BDCs used in electrical energy storage applications are inherently DC–DC converters and they can be isolated type or non-isolated. A BDC comprises of two switches. One of the switch is utilized for voltage step down and allows the power to flow from the DC bus to FES, the second switch is utilized for voltage-boost allowing the power to flow from FES to DC bus.

An equivalent of the circuit depicted in Fig. 1 is shown in Fig. 3. For the purpose of understanding, single phase of the FESS is shown. Input supply is given to rectifier. Rectifier converts AC to DC and then this DC supply is fed to DC bus. The dc bus is allied to the FES machine via switch S1 and switch S2 as depicted in Fig. 2. There are two modes of operations, namely, motor mode and generator mode. When the supply is available, energy is stored in flywheel through BDC. The flywheel starts rotating once it gets energized. This is called motor mode. When the supply is cut off, stored energy in flywheel is returned to DC bus through BDC. This is called generator mode. Here, the switch S2 and diode D1 are used for stepping up the output voltage of the FES. Switching with the help of ZCT is carried out via oscillatory action of LC circuit and it is triggered using an auxiliary switch. The main switches are S1 and S2. and the auxiliary switches are S1A and S2A as depicted in Fig.2. The witch S1 and switch S2 are provided with anti-parallel diode D1 and diode D2 respectively. These 4 switches are triggered in such a manner that the current is allowed to flow via diode which is anti-parallel to the IGBTs whenever the IGBTs are needed to be switched on or switched off.

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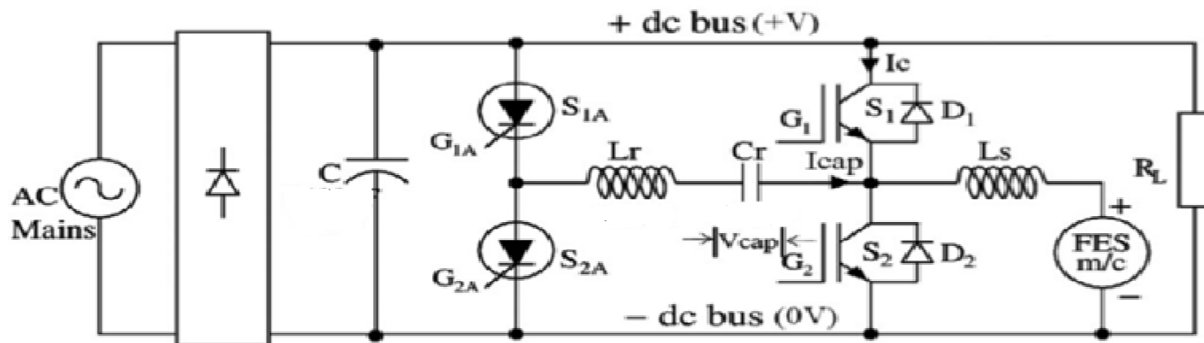


Fig. 3. New ZSPL topology for the BDC

Whenever the voltage across main device is zero, it goes from OFF to ON state and from ON to OFF state when the current becomes zero. This gives an ideal ZSPL switching of the main device. This technique can be used for power transfer from dc bus to FES (buck mode) and from FES to dc bus (boost mode).

### III. SIMULATION RESULTS

The fig. 4 depicts the collector-emitter voltage  $V_{ce}$  and the collector current  $I_c$  of main device S1.

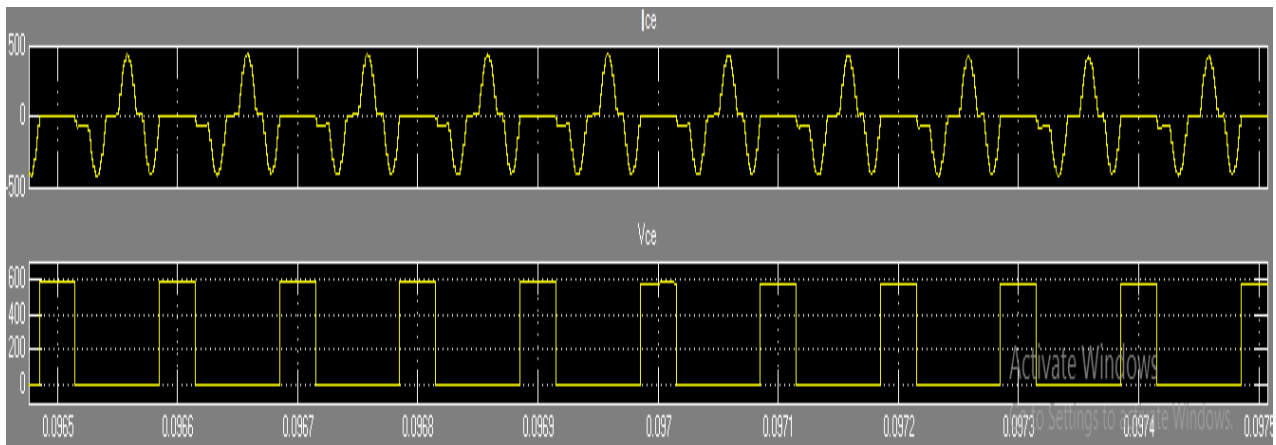


Fig. 4. Simulation Results for Buck Mode

From the simulation results given in above figure, the voltage  $V_{ce}$  drops to 0 V exactly before current  $I_c$  initiates in each period of 0.0001 s. The switching device S1's voltage reduces to zero value before the collector current  $I_c$  starts flowing during turn on transition. This is called zero current switching (ZCS). And the current  $I_{ce}$  through main device S1 reduces to 0 A before voltage across the main device  $V_{ce}$  increases during turn off transition of the main device S1. This is called zero voltage switching (ZVS). This allows the main device S1 to go from OFF to ON state when the voltage  $V_{ce}$  across it is zero and from ON to OFF state when the current  $I_c$  through it is zero. This leads to an ideal ZSPL switching of the device S1.

The transition loss due to stray inductances and IGBT's tail current is eliminated by Zero current switching (ZCS). The transition loss caused by main device S1 output capacitances and diode stored charge is eliminated by zero voltage switching (ZVS).

Similarly, the fig. 5 demonstrate that the current running in the main switching device reduces to zero before the device voltage starts improving during switch off transition of the main device.

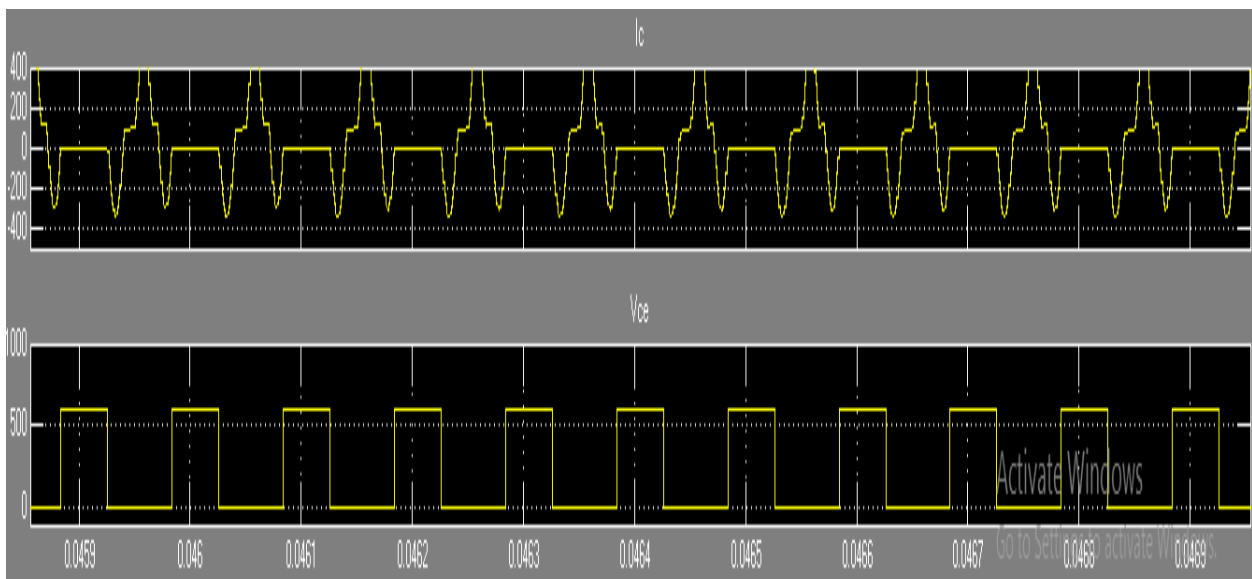


Fig. 5 Simulation Results for Boost Mode

From the simulation results given in above figure, the voltage  $V_{ce}$  drops to 0 V exactly before current  $I_c$  initiates in each period of 0.0001 s. The switching device  $S_2$ 's voltage reduces to zero value before the collector current  $I_c$  starts flowing during turn on transition. This is called zero current switching (ZCS). And the current  $I_{ce}$  through main device  $S_2$  reduces to 0 A before voltage across the main device  $V_{ce}$  increases during turn off transition of the main device  $S_2$ . This is called zero voltage switching (ZVS). This allows the main device  $S_2$  to go from OFF to ON state when the voltage  $V_{ce}$  across it is zero and from ON to OFF state when the current  $I_c$  through it is zero. This leads to an ideal ZSPL switching of the device  $S_2$ .

It is understood from the results depicted in fig. 4 and fig. 5 for buck mode and the boost operation modes that the proposed technique will provide better results over the previous methods.

#### IV. CONCLUSION

This paper has presented a new topology and control method for a Bidirectional Converter application to achieve zero switching power loss during switch on and switch off transitions of the main device. A design technique has been presented and simulation results have been shown. By utilizing the proposed topology energy saving can be done. The saving of energy is observed to be higher in boost mode when compared to that in buck mode. This is because of the fact that in boost method, the currents in the device are higher when compared with buck mode for a similar output. This is a desirable feature for a FES application in light of the fact that the valuable energy stored in the flywheel can be extracted in the boost mode. The proposed configuration has been confirmed and approved with the results obtained after simulation.

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